Hydraulic Shock

WHAT IS HYDRAULIC SHOCK?

Noise in piping systems is never good; it is normally a symptom of a developing system failure. Hammering sounds known as water hammer are the results of damaging vibrations caused by hydraulic shock. While water hammer is annoying, hydraulic shock is a damaging force.

Hydraulic shock is the sudden elevation in line pressure caused by a shock wave created by the sudden change in velocity of a non-compressible liquid (especially water). Most commonly, hydraulic shock occurs when a column of moving water is suddenly stopped. The kinetic energy of motion is changed to pressure energy that has to be absorbed. A shock wave is created within the pipe, traveling back through the liquid until it is stopped and bounced back to the original obstruction. The wave travels back and forth until the energy is dissipated.

Visualize a train locomotive traveling down the tracks until it strikes a wall. Either the locomotive destroys the wall (the water breaks the valve) or the energy rebounds, destroying the locomotive (vibrating the piping) or both.

Hydraulic shock is too often overlooked when valve selections are made. The rapid closing time of quarter-turn valves, swing check valves and actuated valves is as critical a consideration as pressure and temperature limitations if not properly addressed. The cost, ease of operation, and flow capacity of these valves may be quickly overshadowed, if not properly applied, by the costs of replacement and repairs resulting from hydraulic shock.

THE FORCE OF HYDRAULIC SHOCK

The magnitude of hydraulic shock is a function of the amount of mass in motion (or suddenly put in motion), the velocity of the mass, and how quickly the velocity is changed.

Velocity:

The speed of the mass is not the determinate of the magnitude of the shock, but how quickly the speed changes. It is obvious, however, that the higher the velocity, the greater the change in velocity will be when a valve is quickly closed. Using the example of the freight train, the damage to the wall and locomotive will be much less if the locomotive is traveling at 6 mph rather than traveling 60 mph. The shock wave can travel back and forth through water at a rate of 4,000 to 4,500 feet per second (over 2,700 miles per hour). A formula commonly used for a quick estimate of the additional pressure to the system is to multiply the velocity (in feet per second) by 60 psi. Piping systems commonly have flow of 5 to 10 feet per second. Hydraulic shock will result in an additional pressure of 300 to 600 psi using this estimate.
Mass:
In a recent application, hydraulic shock was ripping out the seats and bending (even breaking) 416 stainless steel stems in 6" butterfly valves because the closing and opening times were set too quickly. The velocity of the system was only 3 fps, and the pressure was 60 psi. The shock and system pressure should only have totaled 240 psi (60 psi times 3 fps + 60 psi). This was well below the maximum pressure limits of the valve body and trim materials. The 6" piping upstream of the butterfly valves extended for approximately 1/4 mile. The momentum of the mass of water 6" in diameter, 1/4 mile long, produced a significant force even though it had relatively little velocity. While velocity is the most significant determinate of the magnitude of the shock force, mass is also important. The force of the impact of the locomotive is much greater if there are a hundred freight cars in motion behind it.

The specific gravity of the media is also an important consideration. The greater the density of the mass, the greater the pressure energy will be. The impact of the 100-car freight train will be greater if each car is filled with coal.

Time:
If the locomotive with one hundred freight cars filled with coal, traveling at sixty miles per hour is stopped over a period of fifteen minutes, there will be no noticeable shock wave. But if this train runs into the wall and stops immediately, extensive damage will be done. Therefore, the third element in determining the force of hydraulic shock is the time within which the velocity of the liquid is changed. In the above example of the 6" butterfly valves, the valves were installed with pneumatic actuators with a cycle speed of fifteen seconds from full open to full close. In this case, the fifteen second cycle time was too fast. The valve closure time should have been longer still. The moving mass only caused damage when the velocity was changed too quickly. This situation could have been avoided during the design stage if the length of the piping run and the potential for hydraulic shock were taken into consideration.

The critical closure time for a valve is a function of the length of pipe upstream within which the shock wave will travel and the elasticity of the pipe which effects how rapidly the energy will be absorbed. It is directly related to the time the pressure wave travels back through the pipe and returns to the point of closure. Critical time is calculated as:

\[ T_c = \frac{2L}{a} \]

where:
- \( T_c \) = Critical time of closure
- \( L \) = Length of pipe, in feet, from point of closure to point of relief.
- \( a \) = Velocity of propagation of elastic vibration in the pipe in feet per second.

The time in seconds to close a valve must be greater than twice the length of the upstream pipe. The more rigid the pipe, the slower the valve must close.
THE CAUSE OF HYDRAULIC SHOCK

Hydraulic shock is defined in terms of a “change in velocity” because the sudden acceleration of a liquid as well as the sudden stopping of it can create a shock wave. A quick starting pump or the quick-opening of a valve can cause as much damage as a quick-closing valve. Water under pressure will quickly surge into an empty line, unimpeded, and reach excessive velocities until reaching an elbow, valve or fixture which suddenly stops this forward velocity. Shock can often be traced to the improper operation of a valve. The increased use of quarter-turn valves improperly applied or operated has significantly increased the incidents of hydraulic shock. It is extremely easy to “flip” the lever on a ball or butterfly valve and cause hydraulic shock when the proper operator would have eliminated this potential problem.

By design, ball valves are susceptible to quick opening and closing. Their relatively small size, low torque, and lack of latching makes them easy to quickly flip open or close. The mass is limited by the small size of the piping, but velocities are prone to be higher. Even small lines of relatively low velocities are subject to hydraulic shock as evidenced by the common occurrences of water hammer in the home when a faucet is quickly closed. Joints and supports are weakened over time even at these low level shock waves.

Larger diameter lever operated butterfly valves can be a potential cause of hydraulic shock if not applied or operated properly. Butterfly valves are often used on long lines containing a large volume of fluid. The lever handle makes it very easy to quickly close or open the butterfly valve. The design of the butterfly disc in the waterway results in the velocity and pressure pushing the disc to the closed position quicker than the operator intended. Butterfly valves over the nominal size of 6” should be equipped with a slow closing gear operator to control the tendency of the disc from closing too quickly due to these dynamic forces.

The growing use of quarter-turn valves has also increased the use of automated actuation. Actuation provides the opportunity to control the closing speed of the quarter-turn valve. The critical time of closure should be a primary consideration when sizing the actuator to the valve. The closure must be checked after installation. Closing speeds are controlled in pneumatics using speed control on the exhaust air. Electric actuator speeds are controlled by design of motor and gear train. On butterfly valves, a motor brake is always recommended.

A swing check valve is another quick-closing valve where hydraulic shock can occur if the system is not designed properly. There are swing check valves with the angle of the closure varying many degrees. The most common swing check valves are the 5° seat and the 45° seat. The 5° seat is more susceptible to hydraulic shock than the 45° seat because of the longer travel time it takes to close. Gravity and flow reversal of the downstream liquid closes the disc. When the liquid reverses, it slams the check valve closed and the motion of the liquid is quickly stopped. If the liquid downstream has a significant mass, the sudden halt of this momentum results in a significant hydraulic shockwave. Large stacks are particularly susceptible to this type of shock. As the pump shuts off, the rising fluid stops rising and begins to reverse, slamming a swing check valve closed and creating a significant shock wave. This can result in a bent hanger arm as well as damage to pipe, fittings, hangers and pump. The solution can be a lever and weight or lever and spring installed on swing check valves. Another alternative would be a spring-loaded double door.
or center guided check valve and these designs force the disc closed before the liquid can reverse, causing hydraulic shock.

Unlike water, steam is a compressible gas but it can still be the cause of serious hydraulic shock. The velocity of steam is ten to twenty times that of water. While the maximum velocity of water should be less than 10 fps, steam will commonly travel at 100 to 170 feet per second. Small amounts of liquid condensate can be picked up by steam that is suddenly introduced into the system. The result is a slug of water traveling at 100 fps. Sixty psi times 100 fps equals an additional pressure on the system of 6,000 psi. Personnel must be trained to always open steam valves slowly, allowing any condensate to be pushed out slowly. Large diameter valves should have bypasses installed to allow the slow introduction of steam until the line is clear of condensate.

There are as many causes of hydraulic shock as there are ways to control fluids. If the controls result in a sudden change in the flow, a point of potential problems has been created.

**DETECTION AND PREVENTION**

Sound (water hammer) is the first indication of the presence of hydraulic shock. A banging sound is the symptom of the shock wave traveling through the piping. A strong shock wave will also move the pipes. Fractured iron castings (fittings, valve bodies, and pump casings) are a typical result of severe hydraulic shock. Ductile material like bronze, ductile iron or steel will become distorted. A bronze disc will take a concave shape when the wave strikes the center of a closed valve and will not open. The shock wave caused by a swing check valve will bend the hanger arm and the disc will hang up.

The best preventions of hydraulic shock include the following:

- **Limit the Velocity of Non-Compressible Liquids** – Velocity greater than ten feet per second is a red flag for hydraulic shock. If the upstream lines are long and diameters large, five feet per second becomes more reasonable. For rigid plastic piping, five feet per second is a maximum velocity because of its brittleness. Velocities above these limits must be controlled gently and slowly.

- **Choose the Right Valve** – A lot has been written about the benefits of quarter-turn valves. However, they should never be considered the valve of choice for all applications. The ease of operation can be a two-edge sword; it can be as damaging as it is efficient. Therefore it is extremely important when designing a system that the speed with which a valve operates should be a major consideration. High velocities, long runs and large diameters should raise considerations of opening and closing times. The same considerations should be raised when selecting valves for steam lines. Multi-turn valves, slow closing gear operators and time controlled actuators are options to be considered when selecting the proper valve.

- **Check Valves** – The low pressure drop of flow through a swing check valve makes them an attractive choice. Performance and longevity may be sacrificed to achieve the improved flow. It must be remembered that swing check valves are quick-closing valves and rely on flow reversal to close. Swing check valves assisted with lever & spring or weight can eliminate concerns of hydraulic shock. Spring-loaded...
or other assisted check valves may restrict flow or be more expensive, but this too is an alternative to eliminating hydraulic shock.

- **Other Considerations** – Slow starting pumps should be considered where long runs and large diameter pipe is down-stream. Enlarged areas such as large diameter risers, branches and air chambers in the path of the pressure wave, will help dissipate the energy. Areas of compressible air are good absorbers of energy but they can become displaced with water over time.

The ultimate choice is to prevent or correct sudden changes in the flow of liquids.

**SUMMARY**

Water hammer is the sound resulting from hydraulic shock. The sound and vibration of the piping system is a sure indication that damage is being done to the piping system. The rapid change in the velocity of non-compressible liquids is the cause. Lengths and diameters of the piping and the velocity of the liquid directly affect the magnitude of the shock. How quickly a valve can be opened or closed should be a priority in selection of the right valve for the application.